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ENDURANCE PERFORMANCE OF MODERATE ALTITUDE RESIDENTS DURING INITIAL EXPOSURE TO 4300 M, WITH AND WITHOUT CARBOHYDRATE SUPPLEMENTATION

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This study determined the effect of living at moderate altitude on endurance exercise performance, with and without carbohydrate supplementation (CHOS), during the first 3 days of residence at 4300 m. The experimental trials were conducted in a double-blind manner. Subjects were healthy Air Force Academy (AFA) active duty members (9 men and 6 women; age: 30 ± 1 yrs; mean± SE) who had been living at 1800 to 2200 m for at least 3 months prior to the start of the study. All performed a maximal effort 720 kJ cycle time trial at the AFA and at the summit of Pikes Peak (PP), CO, (4300 m) on Days 1 (PP1) and 3 (PP3). At the start of the time trials at PP, and then every 15 min thereafter, nine subjects drank a 10% CHO solution (0.175 gokg-1 body weight) and six fitness-matched subjects drank a placebo (PLA) solution. All subjects freely adjusted power outputs and drank water ad libitum. Blood glucose, heart rate, arterial oxygen saturation, and ratings of perceived exertion were recorded frequently during exercise. Cycle time did not differ between groups at the AFA (CHOS vs. PLA; 85± 8 vs. 93± 8 min), PP1 (101± 8 vs. 116± 10 min), or PP3 (95± 8 vs. 107± 12 min). For both groups, cycle times on PP1 and PP3 were longer compared to the AFA ($P < 0.01$) and were improved from PP1 to PP3 ($P < 0.03$). There were no between-group differences in any of the measurements during exercise, other than blood glucose (1.5 to 2.0 mmoloL-1 higher for CHOS vs. PLA [$P < 0.01$]). It was concluded that (1) moderate altitude residents had improved endurance performance from PP1 to PP3; (2) CHOS during exercise provided no additional performance benefit; and (3) endurance performance during initial exposure to 4300 m for moderate altitude residents was more than 50% better compared to previously studied low-altitude residents.

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BACKGROUND

Presented here are some results of a collaborative research project titled "Effect of long-term moderate altitude residence on acute mountain sickness susceptibility, and physical and cognitive performances at 4300 m." This research was conducted in support of U.S. Army Science and Technology Objective IV.ME.2004.01 Warfighter Altitude Readiness Strategies. The overall goals of the project were to determine if long-term residence at moderate elevations would reduce acute mountain sickness susceptibility, and ameliorate the decrement in physical and cognitive performances after rapid ascent to the higher elevation of 4300 m.

Participating personnel included scientists and technical staff members of the United States Army Research Institute of Environmental Medicine (USARIEM), United States Air Force Academy (AFA), Oklahoma State University, Kent State University, and The College of William and Mary. Test volunteers were male and female military AFA staff members who had been living in the Colorado Springs, CO, area (1800 to 2200 m) for at least 3 months.

In this report are the results of a major component of the overall project that evaluated endurance exercise performance of moderate altitude residents during their initial exposure to a higher elevation, with and without carbohydrate supplementation during exercise.

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EXECUTIVE SUMMARY

This study determined the effect of living at moderate altitude on endurance exercise performance, with and without carbohydrate supplementation (CHOS), during the first 3 days of residence at 4300 m. The experimental trials were conducted in a double-blind manner. Subjects were healthy Air Force Academy (AFA) active duty members (9 men and 6 women; age: 30 ± 1 yrs; mean±SE) who had been living at 1800 to 2200 m for at least 3 months prior to the start of the study. All performed a maximal effort 720 kJ cycle time trial at the AFA and at the summit of Pikes Peak (PP), CO, (4300 m) on Days 1 (PP1) and 3 (PP3). At the start of the time trials at PP, and then every 15 min thereafter, nine subjects drank a 10% CHO solution (0.175 $g \cdot kg^{-1}$ body weight) and six fitness-matched subjects drank a placebo (PLA) solution. All subjects freely adjusted power outputs and drank water *ad libitum*. Blood glucose, heart rate, arterial oxygen saturation, and ratings of perceived exertion were recorded frequently during exercise. Cycle time did not differ between groups at the AFA (CHOS vs. PLA; 85±8 vs. 93±8 min), PP1 (101±8 vs. 116±10 min), or PP3 (95±8 vs. 107±12 min). For both groups, cycle times on PP1 and PP3 were longer compared to the AFA ($P<0.01$) and were improved from PP1 to PP3 ($P<0.03$). There were no between-group differences in any of the measurements during exercise, other than blood glucose (1.5 to 2.0 $mmol \cdot L^{-1}$ higher for CHOS vs. PLA [$P<0.01$]). It was concluded that (1) moderate altitude residents had improved endurance performance from PP1 to PP3; (2) CHOS during exercise provided no additional performance benefit; and (3) endurance performance during initial exposure to 4300 m for moderate altitude residents was more than 50% better compared to previously studied low-altitude residents.

INTRODUCTION

Maximal exercise capacity of sea-level residents (SLR) progressively decreases as elevation increases (11). As a consequence, the ability to perform at the same work or exercise intensity for prolonged periods of time is reduced at altitude compared to sea level, with the largest reduction demonstrated during initial altitude exposure (11). Results from a recent study (10) showed that carbohydrate supplementation (CHOS) during prolonged cycle exercise partly offset the large endurance-performance reductions of SLR living for 10 days at high altitude (4300 m.) Performance on the third day at altitude compared to that at sea level was reduced by ~70% for the placebo group, but only by ~45% for the fitness-matched CHOS group. By the 10th day, the between-group performance gap had narrowed, but was still 9% better for the CHOS group. While these results clearly indicated that increased availability of CHO as a metabolic fuel enhanced endurance performance of SLR at high altitude, they also indicated that the benefit of CHOS may be reduced with altitude acclimatization. In other words, the many beneficial physiological changes associated with altitude acclimatization may have attenuated the impact of CHOS during prolonged exercise.

Individuals living for extended periods of time at moderate elevations (e.g., 1800 to 3000 m) become "fully" acclimatized to their resident altitude, with a major outcome being improved endurance performance while at altitude (5, 11). There is a paucity of information, however, to determine the extent that acclimatization to moderate elevations will benefit endurance performance during the first few days of exposure to higher elevations. Moreover, in light of our previous finding indicating an inverse relationship between level of altitude acclimatization and benefit of CHOS during prolonged exercise (10), it is not clear if CHOS would improve performance similarly for acclimatized moderate altitude residents (MAR) as it did for unacclimatized SLR exposed to the same higher elevation. The purpose of this study, therefore, was to determine the effect of moderate altitude residence on endurance exercise performance during initial exposure to 4300 m, with and without CHOS.

METHODS

VOLUNTEERS

Military volunteers were recruited using posted advertisement (via physical and virtual bulletin boards, and in military base newspapers) at the AFA, Colorado Springs, CO. All were active duty members from the AFA and were required to have been living in the Colorado Springs metropolitan area (1800 to 2200 m) for at least 3 months prior to the start of the study. If an individual voluntarily expressed an interest in participating in the study, they contacted one of the investigators to schedule a meeting where they had an opportunity to read the institutionally approved Volunteer Agreement Affidavit (VAA), ask questions, talk about availability and scheduling of testing sessions at the AFA and Pikes Peak laboratories, and view photos of the Pikes Peak summit area. If they wanted to participate, they were asked to sign the VAA in the presence of an unbiased representative to document their informed consent. The VAA was consistent

with policies for protection of human subjects, as described in Army Regulation 70-25. The research also was conducted in adherence with the provisions of 45 CFR part 46.

All potential volunteers were required to be between the ages of 18 and 35, participate in regular physical activity, have passed their most recent PT test, have the ability and no aversion to performing strenuous and prolonged cycle exercise, and be willing not to consume alcoholic beverages, or exercise using their legs (e.g., run, bicycle, or weight lift) for at least 24 hr prior to exercise testing or departing to the summit of Pikes Peak. Medical records were reviewed by an assigned Medical Officer. Prior to participation, each also had a physical exam that included routine blood and urine analyses. Volunteers were excluded if they smoked, were on a physical medical profile, or had anemia or hemoglobin S. Volunteers with evidence of any physical, mental, or medical conditions that would make the proposed study relatively more hazardous were excluded. Women volunteers could not be pregnant (negative pregnancy tests were required during screening and just prior to high-altitude exposure).

Approximately 40 individuals were interested in participating. However, after the medical assessments, and explanations of the tests, restrictions, and potential time conflicts, 20 volunteers were ultimately enrolled.

STUDY OVERVIEW

The volunteers reported on 3 separate days to the Human Performance Laboratory at the AFA (594 mmHg, 2200 m) in late June to early July 2004, and for 3 consecutive days at the USARIEM High Altitude Research Laboratory at the summit of Pikes Peak (PP, 458 mmHg, 4300 m) from mid- to late July 2004. Scheduling of exercise test sessions at the AFA and travel to PP to reside for 3 days was dictated primarily by the work and personal schedules of each volunteer. On 1 of the 3 days in each location, the volunteers performed a cycle ergometer peak oxygen uptake ($\dot{V}O_{2\,peak}$) test, and a cycle ergometer endurance test on each of the other 2 days. The endurance tests consisted of a steady-state segment and a time-trial performance segment. Thus, for the entire study, each volunteer performed a total of two $\dot{V}O_{2\,peak}$ tests and four endurance tests. The data collected during the faster of the two time trials conducted at the AFA for each volunteer provided a baseline for comparison to the data collected at Pikes Peak. The same equipment was used at both testing sites.

Every 1 to 3 days during the PP phase, either one or two volunteers were driven by automobile from the AFA (departure at 0830 h) to the summit of PP (arrival at 0930 h). At 1130 h of the first day (PP1), an endurance test was conducted. At PP on Day 2 (PP2) and on Day 3 (PP3), a $\dot{V}O_{2\,peak}$ test and another endurance test, respectively, were conducted at 0800 h.

Volunteers were allowed to eat *ad libitum* throughout the entire study, but were told to fast for a minimum of 12 hr prior to all exercise test sessions. While at PP, the

volunteers consumed only those foods that were similar in volume and composition to what they normally ate at the AFA. In addition, while at the AFA, they were told to maintain their normal exercise conditioning routine, but not to perform any non-study related leg exercise for 24 hr prior to each test session. While living on the summit, the volunteers were strongly encouraged to remain physically active. They were asked to participate in activities such as basketball, soccer, and hacky sack, play catch with a football, baseball, or frisbee, and to go on a 2-hr hike beginning in late morning of PP2. (The trail was within a 5-mile drive from the summit and was more than 3600 m elevation.) Such activities helped maintain a high energy expenditure that is typical of prolonged, military outdoor activities in mountainous terrain.

MEASUREMENTS

Peak Oxygen Uptake

An incremental progressive exercise bout to volitional exhaustion on an electromagnetically braked cycle ergometer (Lode Co., Excalibur Sport, The Netherlands) was used to assess $\dot{V}O_{2\,peak}$ at the AFA and PP2. Volunteers pedaled at 60 to 110 rpm for 2 min at 50 watts (W), 100 W, and then in 30 W increments thereafter until oxygen uptake failed to increase or until volitional fatigue. During the $\dot{V}O_{2\,peak}$ test, oxygen uptake (True Max 2400 metabolic cart, ParvoMedics, Salt Lake City, UT), heart rate (HR, heart rate monitor, Polar Corp., Hempstead, NY; and ECG, AT-6, Schiller Corp., Ontario, Canada), and oxygen saturation (SaO_2, noninvasive finger pulse oximeter, Nellcor N-200, Pleasanton, CA) were monitored continuously, while ratings of perceived exertion [RPE, 6 to 20 Borg Scale (3)] were obtained in the final 15 sec of each 2-min power output interval. Results of the $\dot{V}O_{2\,peak}$ tests were used to (1) set the low and high power outputs during the steady-state exercise segment of each endurance test, and (2) estimate the oxygen costs of the self-selected power outputs used during the time-trial performance segment of the endurance test.

Cycle Ergometer Endurance Test

The cycle endurance exercise test consisted of two distinct segments: a steady-state exercise segment followed by a time-trial performance segment. Throughout the entire endurance test, water was provided *ad libitum*. Endurance tests were performed using electromagnetically braked cycle ergometers (Lode Co., Excalibur, The Netherlands) on 4 separate days: twice at the AFA and twice at PP. Steady-state exercise assessed physiological changes from the AFA to PP and during the 3 days of high-altitude acclimatization. The time-trial assessed performance changes (1) from the AFA to PP, (2) from PP1 to PP3, and (3) due to CHOS during exercise while at high altitude. Volunteers were required to provide maximum effort during all four time-trial performances.

During steady-state exercise, volunteers warmed up for 5 min at 50 W. They then completed two consecutive 20-min exercise bouts at approximately 46% and 59% of their altitude-specific $\dot{V}O_{2\,peak}$, followed by a 5-min rest period to allow for a break

during which the volunteer was permitted to stretch or use the bathroom. Volunteers were then instructed to begin the time-trial in which they were required to complete 720 kJ of total work as fast as possible.[1] Volunteers were allowed, at any time during cycling, to alter pedaling speed and to adjust power output by any desired W increment. This type of performance test was selected because of its high test-retest reproducibility and low coefficient of variance (14). Volunteers were provided real-time feedback (via computer screen graphics) of total work performed and total work remaining. Volunteers were not informed of their time-trial performance durations until the entire study was completed.

All four of the endurance tests were conducted in nearly exactly the same manner. The only exception was that for the two endurance tests at the AFA, there were no blood samples drawn and, in addition to water provided *ad libitum*, water was offered at the exact volume, times, and frequency that the CHO supplement or placebo would be offered during the time-trial performance tests conducted on PP1 and PP3, respectively. Carbohydrate supplementation or placebo was provided only during the time-trial performance tests at PP. Although the CHO or placebo supplement was used only at PP, the designation of "CHO^{+}" or "$placebo^{+}$" group was used while at the AFA to describe the volunteers who *subsequently would be* in either the CHO-supplemented or placebo group at PP.

Because the first endurance test at PP (day 1) was not scheduled to start before 1130 h, the volunteers would be fasting for 15 hr or more before beginning the test. To reduce discomfort but yet minimize the impact of food on time-trial performance, the volunteers were allowed to consume, by 0830 h, a provided commercially available energy bar (e.g., ~ composition = 210 kcal, 7 gm fat, 20 gm CHO, and 16 gm protein). Consuming the bar 3 hr prior to exercise allowed blood glucose and insulin concentrations to return to fasting levels by at least an hour prior to the start of the test (12). The second endurance test at PP (day 3) was initiated at 0800 h after fasting overnight, and no bar was offered.

Carbohydrate and Placebo Group Assignment. After completion of the AFA phase, the volunteers were divided into either a CHO-supplemented (CHOS) or placebo group for the rest of the study. The two groups were matched ($P>0.10$) with respect to age, body weight, height, gender, $\dot{V}O_{2peak}$, and by the faster (i.e., better) of the two times needed to complete the time trials at the AFA. A staff member not directly involved with any exercise testing assigned each volunteer to the groups. Neither the volunteers nor the investigators directly participating in the endurance tests knew the group assignments until the entire study was completed.

Carbohydrate and Placebo Supplementation. The CHO supplement was a tropical punch or lemon-lime flavored (volunteer's choice) blend of maltodextrin

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[1]One volunteer in the placebo group, who had the lowest $\dot{V}O_{2peak}$ and was the most sedentary in the study, was required to perform only 360 kJ (i.e., one half of 720 kJ) of total work. This was done to allow the time-trial duration to be similar to that of the other volunteers and to assure task completion.

(mass•volume^{-1}, 9%), glucose (2%), and fructose (1%) (Ergo Drink, U.S. Army Soldier Systems Command, Natick, MA), previously reported to be highly acceptable (15). Each powdered serving was reconstituted with water to a 10% CHO solution. At PP, at the start of the time-trial performance segment and every 15 min thereafter until completion, volunteers consumed either 0.175 g•kg^{-1} body weight (e.g., 80 kg b.w. = 14 g CHO per serving) of reconstituted Ergo Drink or an equal volume of indistinguishable placebo. A staff member not directly involved with the time-trial tests mixed the CHO and placebo drinks. The volunteer and the investigators participating in the study remained blinded to the supplement assignment until the entire study was completed. The rate of CHO ingested during exercise (e.g., 56 g•hr^{-1} for a volunteer weighing 80 kg) was within established supplementation guidelines (1).

Blood Measures. Blood glucose and lactate (i-Stat, Abbott Diagnostics, Abbott Park, IL) were determined at rest, and after 15 min of cycling at 46% and then after 15 min of cycling at 59% of $\dot{V}O_{2\,peak}$ during steady-state exercise at PP. Blood samples were also obtained after the volunteer completed 25% (i.e., 180 kJ), 50% (i.e., 360 kJ), 75% (i.e., 520 kJ), and at exercise completion (i.e., 100% or 720 kJ) during the time trials at PP. Volume of blood withdrawn for each blood sample was less than 4 ml. The maximum total volume of blood withdrawn for each endurance test at PP was less than 30 ml.

Other Measures and Comparisons to Previous Studies. During all endurance tests, SaO_2 (noninvasive finger pulse oximeter, Nellcor N-200, Pleasanton, CA) and HR (heart rate monitor, Polar Corp, Hempstead, NY) were monitored continuously, and RPE (6 to 20, Borg Scale [3]) were obtained every 5 min. Standard respiratory data (True Max 2400 metabolic cart, Parvo Medics, Salt Lake City, UT) were collected at rest, and within the 10th to 15th min at 46% $\dot{V}O_{2\,peak}$ and 59% $\dot{V}O_{2\,peak}$, respectively, during steady-state exercise.

Because nearly identical procedures and staff were used in the present study as in a recent study of unacclimatized SLR who lived at PP for 10 days (10), the time-trial results of both studies were compared. Performance results from the present study also were compared to published data of low-altitude, highly conditioned individuals who were acclimatized to similar elevations (~2200 m and 4300 m) for approximately 10 days prior to sporting events that lasted more than 2 hr (11). Such comparisons provided a means to determine potential benefits of long-term, moderate altitude residence on endurance performance during initial exposure to 4300 m.

STATISTICS

A two-factor (days x group) analysis of variance with repeated measures on one factor (days) was utilized for performance, physiological, and blood value comparisons. Post hoc analyses (Neuman-Keuls) were performed when appropriate. Independent t-tests were used to compare specific characteristics (e.g., age, height) between groups. Regression analyses were used to determine the relationship between $\dot{V}O_{2\,peak}$ and

time-trial performance at the AFA and PP. Statistical significance was accepted when $P < 0.05$. All values are expressed as means ± SE unless otherwise indicated.

RESULTS

VOLUNTEER WITHDRAWALS AND INJURIES

Prior to departing to PP, three volunteers withdrew for personal reasons not directly involved with the study. Of the remaining 17 volunteers, 10 were to be in the CHOS group and 7 were to be in the placebo group at PP. After arriving at PP, one volunteer in the CHOS group had severe acute mountain sickness during the time trial and could not complete it, and decided to withdraw from the study; one volunteer in the placebo group developed a hamstring muscle cramp during the first time trial on PP1 and did not complete it, but did complete all other exercise tests at PP without incident. Therefore, resting $\dot{V}O_2$, $\dot{V}O_{2\,peak}$, and the low (46% $\dot{V}O_{2\,peak}$) and high (59% $\dot{V}O_{2\,peak}$) steady-state analyses were performed using 9 volunteers in the CHOS group and 7 volunteers in the placebo group; but the time-trial analyses were performed using 9 volunteers from the CHOS group and only 6 volunteers from the placebo group.

There was no between-group difference in mean age, body weight, height, $\dot{V}O_{2\,peak}$, and time to complete the time trial at the AFA, as well as the gender proportion, as shown in Table 1.

Table 1. Physical Characteristics for Both Groups of Volunteers at the AFA.

Group:	Age (yrs)	Weight (kgs)	Height (cm)	Gender	$\dot{V}O_{2\,peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Time (min)
PLA^+	31.0 ± 2	69.5 ± 3	169.6 ± 4	4M, 3W	39.3 ± 3	92.7 ± 8
CHO^+	30.0 ± 1	69.2 ± 3	176.4 ± 3	5M, 4W	43.4 ± 3	85.1 ± 8

Values are means ± SE; PLA^+ and CHO^+ = Volunteers selected at the AFA to be in either the placebo or CHO-supplemented group during the time trials at Pikes Peak.

MEASUREMENTS

Peak Oxygen Uptake, Heart Rate and Arterial Oxygen Saturation

Peak oxygen uptake and its reduction from the AFA did not differ between groups at PP (Table 2). For both groups, $\dot{V}O_{2\,peak}$ declined ~14% from the AFA to PP2 ($P<0.01$). Peak heart rate and peak SaO_2 were lower for both groups on PP2 compared to the AFA ($P<0.01$), and were similar for both groups at the AFA and PP2.

Table 2. Peak Values for Oxygen Uptake, Heart Rate and Arterial Oxygen Saturation at the Air Force Academy and Pikes Peak.

	Air Force Academy		Pikes Peak, Day 2	
Measure:	**PLA$^+$**	**CHO$^+$**	**PLA$^+$**	**CHO$^+$**
$\dot{V}O_{2\,peak}$ **(ml•min•kg^{-1})**	39.3 ± 3	43.4 ± 3	33.6 ± 2*	38.4 ± 3*
HR_{peak} **(beats•min^{-1})**	177 ± 3	182 ± 3	167 ± 4*	172 ± 4*
SaO_{2peak} **(%)**	90.9 ± 1	92.4 ± 1	79.1 ± 1*	80.4 ± 2*

Values are means ± SE; PLA$^+$ and CHO$^+$ = Volunteers selected to be in either the placebo or CHO-supplemented group during the time trial at Pikes Peak. *P<0.01 from Air Force Academy.

Cycle Ergometer Endurance Test

Steady-State Exercise. There were no between-group differences in any of the measurements at the AFA or for either endurance test on PP (Table 3). Power outputs were reduced similarly at PP for both groups (P<0.01). The low steady-state power output at the AFA became the high steady-state power output at PP (because of the reduction in $\dot{V}O_{2\,peak}$ at PP). Throughout the study, the low and the high steady-state exercise intensities were maintained at approximately 46% and 59% of $\dot{V}O_{2\,peak}$. Heart rate and SaO_2 responses to steady-state exercise were lower at PP than at the AFA (P<0.01), whereas RPE was maintained at both testing locations. Blood levels of glucose and lactate did not differ from PP1 to PP3.

Table 3. Steady-State Exercise Values at the Low and High Power Outputs.

	AFA		PP1		PP3	
Measure:	**PLA$^+$**	**CHO$^+$**	**PLA**	**CHO**	**PLA**	**CHO**
PO (watts), low	83±11	100±8	64±9**	82±11**	60±0**	82±11**
PO (watts), high*	110±12	128±9	82±11**	100±8**	82±11**	100±8**
% $\dot{V}O_{2\,peak}$, low	45.4±1	48.2±1	44.2±1	45.6±1	44.6±2	47.6±2
% $\dot{V}O_{2\,peak}$, high*	58.5±1	58.6±1	54.5±3	60.2±3	56.4±2	63±3
HR (beats•min^{-1}), low	125±3	125±4	116±5**	115±5**	116±5**	120±3**
HR (beats•min^{-1}), high*	142±5	144±4	133±6**	139±5**	131 ±4**	136±3**
%SaO_2, rest	96±1	96±1	86±1**	86±1**	88±1**	86±1**
%SaO_2, low	94±1	93±1	81±1**	80±1**	82±1**	80±1**
%SaO_2, high	93 ±1	93±1	79±1**	79±1**	80±1**	78±2**
RPE, low	10±1	10±1	10±1	8±1	11±1	10±1
RPE, high*	12±1	12±1	12±1	11±1	12±1	11±1
Glucose (mmol•L^{-1}), low			5.19±0.17	4.86±0.13	5.27±0.14	5.24±0.27
Glucose (mmol•L^{-1}),high			5.14±0.26	4.93±0.10	5.07±0.27	4.81±0.08
Lactate (mmol•L^{-1}), low			2.6±0.4	3.0±0.5	2.5±0.4	2.5±0.3
Lactate (mmol•L^{-1}), high*			3.4±0.5	4.1±0.8	3.0±0.5	3.6±0.5

Values are means ± SE; PLA$^+$ and CHO$^+$ = Volunteers selected to be in either the placebo or CHO-supplemented group during the time trial at Pikes Peak. AFA = Air Force Academy, PP1 or PP3 = Pikes Peak, Day 1 or Day 3, PO = power output, $\dot{V}O_{2\,peak}$ = peak oxygen uptake, HR = heart rate, SaO_2 = arterial oxygen saturation, RPE = ratings of perceived exertion. *P<0.01 from low exercise intensity. **P<0.01 from AFA.

Time-Trial Performance Segment

Blood Withdrawal Problems. Venous blood samples obtained via catheter for the determination of glucose and lactate values were scheduled to be drawn after 25%, 50%, 75%, and 100% of completion during the two time trials at PP. However, for the majority of volunteers, there were problems either in placing the catheters on at least 1 of the 2 test days, or in successfully drawing all samples from a catheter during a time trial. Therefore, only blood samples obtained within 3 min after completion of the time trials (typically via venipuncture) are reported. These values are compared to resting values obtained prior to supplementation for each group and are reported in Table 4.

Blood Glucose and Lactate. Resting glucose and lactate values did not differ between groups just prior to the time trial. After the time trial, glucose level for the CHOS group was nearly 40% higher than for the rest group. In contrast, glucose level for the placebo group did not differ from the rest group. This finding indicates that oral CHOS was successful in raising blood glucose levels during the time trial. Post-time-trial lactate values were higher for both groups at the end of exercise, and were higher for those on PP3 than on PP1 (P<0.03).

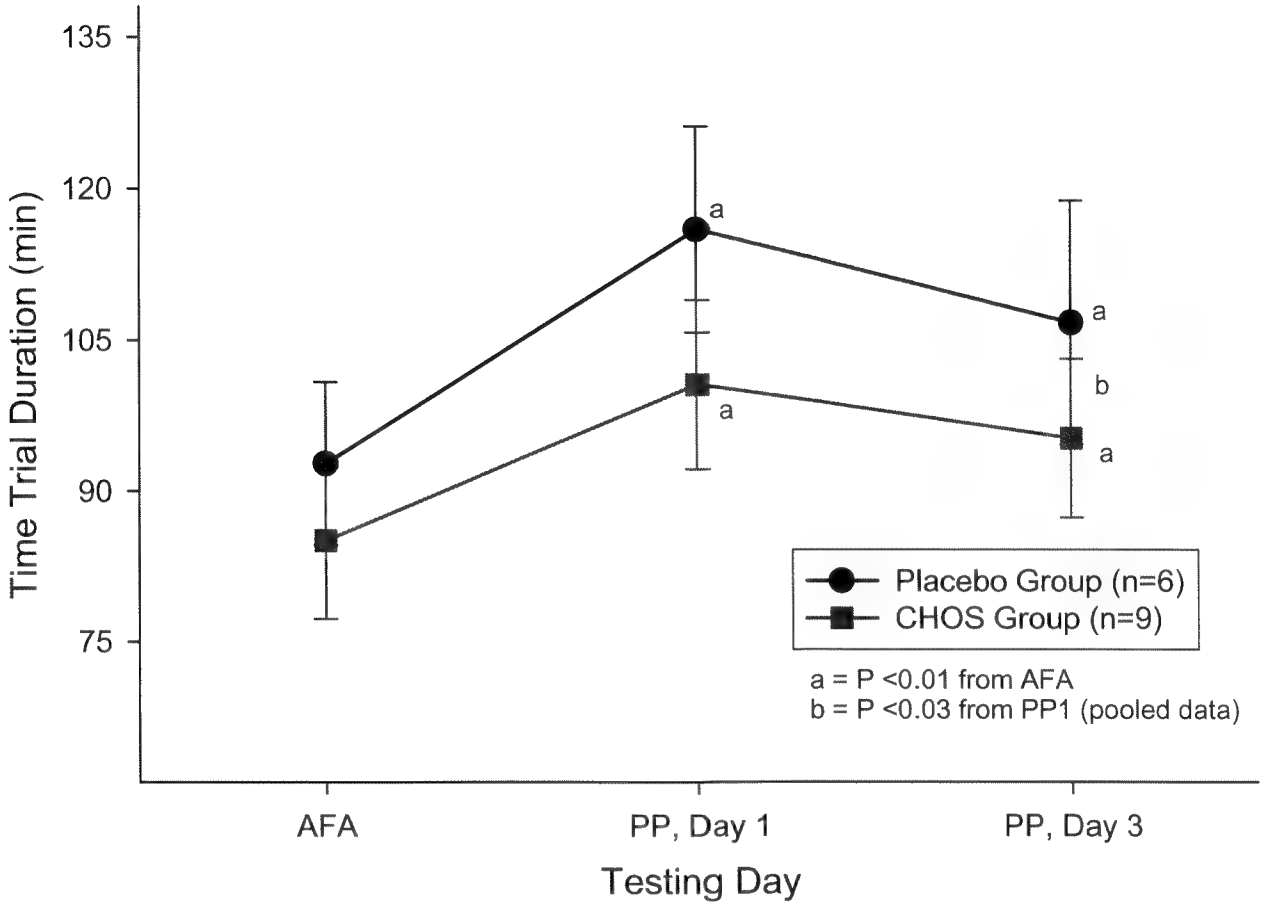
Table 4. Venous Blood Glucose and Lactate Values Obtained at Rest and at Completion of the Time Trials at PP.

	PP1		PP3	
Measure:	**PLA**	**CHOS**	**PLA**	**CHOS**
Glucose (mmol•L^{-1}), Rest	5.04 ± 0.1	4.96 ± 0.1	5.32 ± 0.1	4.96 ± 0.2
Glucose (mmol•L^{-1}), 100%	4.75 ± 0.3	6.61 ± 0.2†,‡	4.96 ± 0.3	6.92 ± 0.3†,‡
Lactate (mmol•L^{-}1), Rest	1.10 ± 0.1	1.40 ± 0.2	1.70 ± 0.2	1.50 ± 0.2
Lactate (mmol•L^{-1}), 100%	4.90 ± 0.9†	4.70 ± 0.7†	6.80 ± 0.7†	7.70 ± 0.7†

Values are means ± SE; PLA = placebo group, CHOS = carbohydrate supplemented group, PP1 or PP3 = Pikes Peak, Day 1 or Day 3. †P<0.01 from rest. ‡P<0.01 from placebo.

Time-Trial Performance. Time-trial performance did not differ between groups at the AFA, or on either day at PP. Each group experienced an increase in time-trial duration at Pikes Peak compared to the AFA (Figure 1). When the data were pooled, the mean time-trial duration increased from 88.1 ± 6 min at the AFA to 106.7 ± 7 min (21.8 ± 3%, P<0.01) on PP1 and to 99.8 ± 7 min (13.5%, P<0.01) on PP3. The reduction in time-trial duration from PP1 to PP3 was statistically significant (P<0.03).

Figure 1. Time-trial performance at the Air Force Academy and Pikes Peak



TIME-TRIAL PERFORMANCE MEASURES

During the time trials at the AFA or for both days at PP, there were no differences between the placebo and CHOS groups in absolute (watts) or relative ($\%Watts_{peak}$) values for power output, $\%\dot{V}O_{2\,peak}$, %SaO2, RPE, or in absolute ($beats \cdot min^{-1}$) or relative ($\%HR_{peak}$) values for HR. These data are presented in Table 5.

Table 5. Measures Associated with Time-Trial Performance at the AFA and PP.

	AFA		PP1		PP3	
Measure:	**PLA$^+$**	**CHO$^+$**	**PLA**	**CHOS**	**PLA**	**CHOS**
Watts (absolute load)	124 ± 19	158 ± 16	109 ± 19	131 ± 11	122 ± 23	142 ± 14
Watts (%Watts$_{peak}$)	50.4 ± 5	58.6 ± 3	50.7 ± 5	56.3 ± 2	56.4 ± 7	60.5 ± 2
% $\dot{V}O_{2\,peak}$	56.8 ± 4	62.9 ± 3	60.3 ± 3	68.3 ± 3	65.0 ± 6	72.8 ± 2
SaO_2 (%)	93.0 ± 1	91.6 ± 1	79.9 ± 1**	78.7 ± 1**	81.1 ± 1**	79.4 ± 1**
RPE	15.3 ± 0.4	14.1 ± 0.5	15.7 ± 0.3	15.3 ± 0.4	15.3 ± 0.4	14.4 ± 0.5
HR (beats•min^{-1})	153 ± 9	160 ± 5	148 ± 5	159 ± 3	145 ± 6	158 ± 4
HR (%HR$_{peak}$)	86.2 ± 4	87.6 ± 2	89.4 ± 1	92.5 ± 1	87.5 ± 2	91.5 ± 2

Values are means ± SE; PLA$^+$ and CHO$^+$ = Volunteers selected to be in either the placebo or CHO-supplemented group during the time trials at Pikes Peak. AFA = Air Force Academy, PP1 or PP3 = Pikes Peak, Day 1 or Day 3, $\dot{V}O_{2\,peak}$ = peak oxygen uptake, SaO_2 = arterial oxygen saturation, RPE = ratings of perceived exertion, HR = heart rate. ** P<0.01 from AFA.

Because there were no between-group differences due to supplementation (other than the expected higher glucose level in the CHOS group at PP), the data of the two groups were pooled. The pooled data are presented in Table 6.

Table 6. Time-Trial Exercise Values for all Volunteers at the AFA and PP.

Measure:	**AFA**	**PP1**	**PP3**
Watts (absolute load)	144 ± 13	122 ± 10**	134 ± 12*
Watts (%Watts$_{peak}$)	54.4 ± 3	50.0 ± 3	59.0 ± 3
% $\dot{V}O_{2\,peak}$	59.9 ± 3	65.4 ± 2**	70.0 ± 3*,**
SaO_2 (%)	92.1 ± 1	79.2 ± 1**	80.1 ± 1**
RPE	14.6 ± 0.4	15.4 ± 0.3**	14.8 ± 0.4*
HR (beats•min^{-1})	157 ± 5	155 ± 3	153 ± 4
HR (%HR$_{peak}$)	87.0 ± 2	91.3 ± 1**	89.9 ± 1

Values are means ± SE, n = 15, AFA = Air Force Academy, PP1 or PP3 = Pikes Peak, Day 1 or Day 3, $\dot{V}O_{2\,peak}$ = peak oxygen uptake, SaO_2 = arterial oxygen saturation, RPE = ratings of perceived exertion, HR = heart rate. *P<0.05 from PP1. ** P<0.01 from AFA.

Self-selected power output was reduced on PP1 compared to the AFA, and then increased on PP3 to a level that did not differ significantly (P =0.069) from the AFA. Relative power output (i.e., %Watts$_{peak}$) used during the time trials did not differ among test days. In contrast, the % $\dot{V}O_{2\,peak}$ was higher on both days at PP compared to the AFA, and was higher on PP3 than on PP1. Arterial oxygen saturation was lower for both PP test days compared to the AFA, with no difference between PP days. Ratings of perceived exertion increased from the AFA to PP1, and then decreased to the same level on PP3 as at the AFA. Heart rate remained stable among test days at approximately 155 beats•min^{-1}. Percentage of HR_{peak} used was higher on PP1 compared to the AFA, and tended to decrease from PP1 to PP3 (P = 0.063).

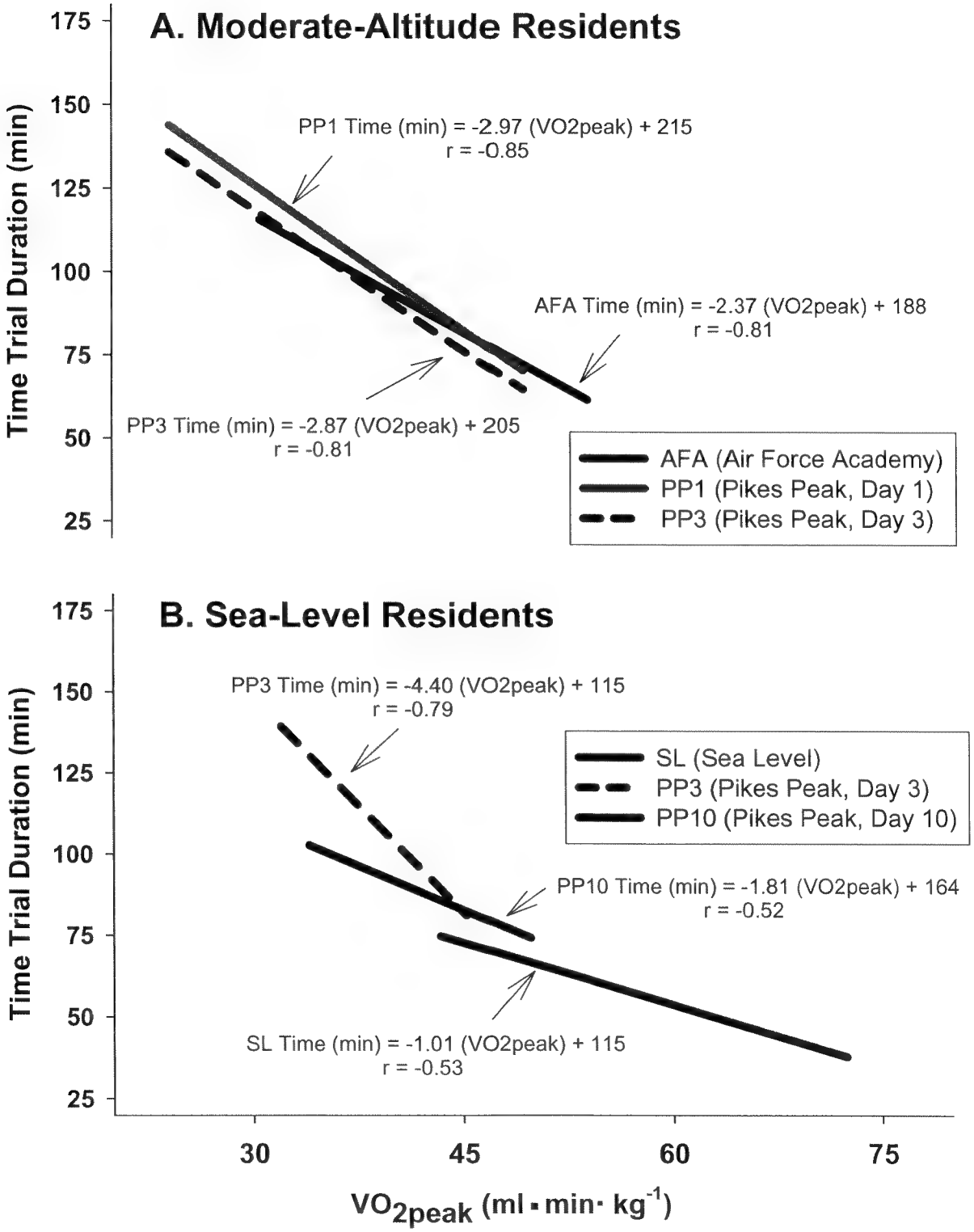
PERFORMANCE COMPARISONS TO PREVIOUSLY PUBLISHED REPORTS

Regression lines in Figure 2 depict the inverse relationships between $\dot{V}O_{2\,peak}$ and time-trial performance of acclimatized (Panel A) and unacclimatized (Panel B) individuals rapidly exposed to 4300 m. In Panel A are data collected in the present study from MAR at the AFA, and on PP1 and PP3. In Panel B are data collected from SLR at SL, and on PP3 and PP10 (10). Please note that the data in Panels A and B are plotted using the identical range of values for the X and Y axes.

Most noteworthy in Panel A are the similarities in slopes, intercepts, and correlation coefficients among test days for MAR. The leftward shift for the PP lines relative to the AFA line is due to the sustained ~14% reduction in $\dot{V}O_{2\,peak}$ from AFA to PP. Both PP lines also are parallel to each other, with the PP1 line slightly above the PP3 line; a difference resulting from the volunteers cycling at a reduced power output--and thereby a longer time-trial duration---on PP1 compared to PP3 ($P<0.03$).

In Panel B, the spatial orientation of the lines to each other is quite different from what is depicted in Panel A. For example, the PP3 line has a slope that is more than four times steeper and is shifted greatly to the left, compared to SL. These differences are due to the measured 70% increase in time-trial duration and a 26% reduction in $\dot{V}O_{2\,peak}$, respectively. From PP3 to PP10, the slope decreased by more than half because of the 25% improvement in time-trial performance. However, despite greatly improved time-trial performance from PP3 to PP10, the PP10 line still remained above SL. Thus, unlike in Panel A in which the matching of $\dot{V}O_{2\,peak}$ values among MAR at AFA and PP resulted in similar time-trial performances at each location, the matching of $\dot{V}O_{2\,peak}$ values among SLR at SL and PP resulted in a more prolonged time-trial duration at PP that cannot be explained only by the high-altitude reduction in $\dot{V}O_{2\,peak}$. These findings suggest that the level of acclimatization acquired even after 10 days of residence at 4300 m for SLR is not as complete or beneficial as that acquired after living for 3 months or longer at a moderate elevation for subsequent performance at 4300 m.

Figure 2. Relationship of peak oxygen uptake and time-trial duration



The benefits of acclimatization due to living at a moderate elevation for subsequent high-altitude exposure also can be assessed by comparing the three indices of exercise intensity collected during the time-trial performance tests for MAR and SLR: $\%\dot{V}O_{2\,peak}$, $\%Watts_{peak}$ and $\%HR_{peak}$. For example, as shown in Table 7, each of the intensity indices was decreased or tended to decrease for SLR on PP3 before recovering towards their SL baseline value on PP10. In contrast, MAR did not experience a decline in any of the intensity indices on either day at PP compared to AFA baseline. On PP3, the only directly comparable day between the MAR of the present study and the SLR of the previous study (10), the MAR were able to exercise at a higher intensity and had a higher SaO_2 (a primary indicator of altitude acclimatization). Interestingly, the value for SaO_2 for the MAR after only 1 day at PP was similar to that of the SLR after their 10 days at PP. Overall, these observations suggest that the time-trial performance at PP of MAR, which was less impaired compared to that of SLR, is directly associated with the maintenance of exercise intensity at 4300 m that, in turn, relates to a greater level of acclimatization (as indicated by a higher SaO_2).

Table 7. Indices of Exercise Intensity and Acclimatization During the Time Trials.

	SL baseline	AFA baseline	PP1	PP3	PP10
$\%\dot{V}O_{2\,peak}$ SLR	60 ± 4			57 ± 4	66 ± 3*
$\%\dot{V}O_{2\,peak}$ MAR		57 ± 4	60 ± 3	65 ± 6	
$\%Watts_{peak}$ SLR	58 ± 4			44 ± 4*	55 ± 3
$\%Watts_{peak}$ MAR		50 ± 5	51 ± 5	56 ± 7	
$\%HR_{peak}$ SLR	82 ± 3			77 ± 3	86 ± 3**
$\%HR_{peak}$ MAR		86 ± 4	89 ± 1†	88 ± 2†	
SaO_2 (%) SLR	96 ± 1			75 ± 3*	82 ± 1**
SaO_2 (%) MAR		93 ± 1	80 ± 1*	81 ± 1*,‡	

Values are means ± SE. SLR = sea level residents, n = 8, placebo group, from reference (10); MAR = moderate altitude residents, n = 9, placebo group, present study. PP1, PP3, or PP10 = Pikes Peak, Day 1, Day 3, or Day 10, HR = heart rate (beats/min). *P<0.05 from associated SL or AFA baseline. **P<0.05 from Day 3. †P < 0.01 from $\%HR_{peak}$ SLR, Day 3. ‡P < 0.01 from $\%SaO_2$ SLR, Day 3.

The benefits of acclimatization acquired while living at 2200 m for 3 months or longer on endurance performance during the first few days of exposure to 4300 m elevation also can be estimated by comparing the results of the present study to compiled athletic event data of previous studies (11). For performance impairments in events lasting longer than 2 hours (a duration similar to that in present study), comparisons were made between a group of low-altitude residents who lived for ~10 days at 2200 m before competing at 2200 m and another group of low-altitude residents

who lived ~10 days at 4300 m before competing at 4300 m. The impairment in performance between 2200 m to 4300 m was estimated as 45% (11). In the present study, compared to performance at the AFA, there was a ~22% impairment on PP1 that was reduced to ~14% on PP3. In other words, the performance impairment for MAR is estimated to be 50% to 70% less during the first few days at 4300 m compared to that of low-altitude residents who had been living at 2200 m and 4300 m for at least 10 days.

DISCUSSION

The three major findings of this study relate to MAR exposed for the first 3 days at 4300 m: (1) CHO supplementation had little impact on time-trial performance, (2) exercise intensity during the time trial was well maintained compared to that at 2200 m, and (3) time-trial performance during initial exposure to 4300 m was estimated to be 50% or better than that of previously studied low-altitude residents.

At the start of endurance exercise, most CHO oxidation is derived from muscle glycogen (8). As exercise continues, the relative contribution to total CHO oxidation provided by muscle glycogen decreases and that provided by blood glucose increases (6). When resting glycogen stores are replete, the rate of total CHO oxidation is similar for CHO-supplemented and placebo groups for 2 1/2 hr of cycling at ~70% $\dot{V}O_{2\,peak}$ (8). After about this time, with no CHO supplementation, muscle glycogen stores become about 60% lower, and glucose levels soon begin to decline relative to resting levels. Since the primary source of blood glucose (i.e., liver glycogen) is limited and blood glucose utilization is related curvilinearly to exercise intensity (4), endurance performance at high intensities will likely be impaired if blood glucose falls (7, 8, 13). Therefore, ingesting CHO to maintain blood glucose levels during prolonged and intense exercise typically improves endurance performance (6).

In the present study, throughout the moderate and high-altitude phases, there was no change in body weight (16), indicating that energy intake equaled energy expenditure. Also, the volunteers maintained the composition of their *ad libitum* mixed diets similarly at both locations. These findings are consistent with the idea that at the start of the endurance tests, resting glycogen stores for each individual were not likely different or greatly reduced from fully replete levels. In addition, for the placebo group, blood glucose during the time trial was maintained above resting levels. Therefore, one reason that CHO supplementation may not have benefited time-trial performance at high altitude was that CHO availability was not a limitation to performance (2, 9).

Another possible reason that CHO supplementation had little effect on performance at 4300 m relates to a large carryover of acclimatization that was apparently acquired while living at moderate elevations. The data presented in Figure 2 and Table 7 offer strong evidence that living at moderate elevations provided sufficient acclimatization such that exercise intensity during the first few days of exposure to 4300 m could be well maintained compared to that at 2200 m. In fact, for both the placebo

and CHO-supplemented groups, there was little change in endurance performance at 4300 m that could not be explained by the high-altitude-induced reduction in $\dot{V}O_{2\,peak}$. Moreover, the level of acclimatization acquired while living at moderate elevations was estimated to provide a 50% or greater performance benefit when compared to lowlanders who were acclimatized for ~10 days to similar elevations (11). Therefore, under conditions of the present study, and in light of our previous findings of an inverse relationship between degree of acclimatization and advantage due to CHO supplementation (10), it is likely that the many beneficial physiological changes associated with moderate altitude acclimatization at least partly attenuated the favorable impact of increasing glucose availability and oxidation during endurance exercise at 4300 m.

CONCLUSIONS

Two matched groups of volunteers who had been living for at least 3 months at moderate elevations ranging from 1800 to 2200 m were rapidly transported to the summit of Pikes Peak (4300 m) where they lived for 3 days. On the first and third day at Pikes Peak, the effects of CHOS (10% solution every 15 min) on time-trial performance were assessed. During the time trials, blood levels of glucose and lactate, heart rate, arterial oxygen saturation, and ratings of perceived exertion were measured repeatedly. Carbohydrate supplementation raised blood glucose levels during exercise, yet both the carbohydrate and placebo groups had similar physiological responses during exercise, and there was no between-group difference in performance. We conclude that CHOS had little effect during exercise for MAR exposed to a higher elevation. We also conclude that living at moderate elevations provides sufficient acclimatization such that exercise intensity during the time trial was well maintained compared to that at moderate elevations. Moreover, endurance performance during the first 3 days of exposure to 4300 m for MAR was at least 50% better compared to previous reports of low-altitude residents exposed to the same elevations.

REFERENCES

1. American College of Sports Medicine, American Dietetic Association and Dietitians of Canada. Nutrition and athletic performance. *Med. Sci. Sports Exerc.* 32: 2130-2145, 2000.
2. Bjorkman O., K. Sahlin, L. Hagenfeldt, and J. Wahren. Influence of glucose and fructose ingestion on the capacity for long-term exercise. *Clin. Physiol.* 4: 483-494, 1984.
3. Borg, G. A. V. Psychophysical basis of perceived exertion. *Med. Sci. Sports Exerc.* 14: 377-381, 1982.
4. Brooks, G. A., and J. Mercier. The balance of carbohydrate and lipid utilization during exercise: the "crossover" concept. *J. Appl. Physiol.* 76: 2253-2261, 1994.
5. Buskirk, E. R., J. Kollias, R. F. Akers, E. K. Prokop, and E. P. Reategui. Maximal performance at altitude and on return from altitude in conditioned runners. *J. Appl. Physiol.* 23: 259-266, 1967.
6. Coggan, A. R., and E. F. Coyle. Carbohydrate ingestion during prolonged exercise: Effects on metabolism and performance. In: *Exercise and Sport Sciences Reviews*, edited by J. O. Hollosky. Philadelphia, PA: 1991, p. 1-40.
7. Coggan, A. R., and E. F. Coyle. Reversal of fatigue during prolonged exercise by carbohydrate infusion or ingestion. *J. Appl. Physiol.* 63: 2388-2395, 1987.
8. Coyle, E. F., A. R. Coggan, M. K. Hemmert, and A. C. Ivy. Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. *J. Appl. Physiol.* 61: 165-172, 1986.
9. Coyle, E. F., J. M Hagberg, B. F. Hurley, W. H. Martin, A. A. Ehsani, and J. O. Hollosky. Carbohydrate feedings during prolonged strenuous exercise can delay fatigue. *J. Appl. Physiol.* 55: 230-235, 1983.
10. Fulco, C. S., K. W. Kambis, A. Friedlander, P. B. Rock, J. S. Staab, R. Soares, D. W. DeGroot, M. Ardelt, S. R. Muza, B. A. Beidleman, A. Grediagin, S. F. Lewis, and A. Cymerman. *Carbohydrate supplementation improves time-trial cycle performance at 4300 m altitude.* Natick, MA: USARIEM. Technical Report T-03/07, February 2003.
11. Fulco, C. S., P. B. Rock, and A. Cymerman. Maximal and submaximal exercise performance at altitude. *Aviat. Space Environ. Med.* 69: 793-801, 1998.
12. Hertzler, S. R., and Y. Kim. Glycemic and insulinemic responses to energy bars of differing macronutrient composition in healthy adults. *Med. Sci. Monit.* 9: CR84-CR90, 2003.
13. Ivy, J. L., D. L. Costill, W. J. Fink, and R. W. Lower. Influence of caffeine and carbohydrate feedings on endurance performance. *Med. Sci. Sports* 11: 6-11, 1979.
14. Jeukendrup, A., W. H. M. Saris, F. Brouns, and A. D. M. Kester. A new validated endurance performance test. *Med. Sci. Sports Exerc.* 28: 266-270, 1996.
15. Montain, S. J., S. M. McGraw, W. J. Tharion, F. M. Kramer, and R. W. Hoyt. *Acceptability of carbohydrate drinks during the Marine Corps infantry officer course 10-day field training exercise.* Natick, MA: USARIEM. Technical Report T-00-2, February 1999.

16. Staab, J. E., C. S. Fulco, M. Zupan, S. R. Muza, P. B. Rock, B. A. Beidleman, and A. Cymerman. Acclimatization responses in moderate-altitude residents compared to sea-level residents at 4300 m. *Med. Sci. Sports Exerc. (Abstract),* 2005.